EL HORNERO
REVISTA DE ORNITOLOGÍA NEOTROPICAL

Establecida en 1917
ISSN 0073-3407

Publicada por Aves Argentinas/Asociación Ornitológica del Plata
Buenos Aires, Argentina

The effects of habitat heterogeneity on avian density and richness in soybean fields in Entre Ríos, Argentina

Goijman, A. P.; Zaccagnini, M. E.

2008

THE EFFECTS OF HABITAT HETEROGENEITY ON AVIAN DENSITY AND RICHNESS IN SOYBEAN FIELDS IN ENTRE RÍOS, ARGENTINA

ANDREA P. GOIJMAN [1,3,4] AND MARÍA ELENA ZACCAGNINI [2,3]

[1] *Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires.*
[2] *Grupo Biodiversidad y Gestión Ambiental, Proyectos Internacionales, Instituto Nacional de Tecnología Agropecuaria (INTA). Cerviño 3101, 1425 Buenos Aires, Argentina.*
[3] *Current Address: Grupo Biodiversidad y Gestión Ambiental, Instituto de Recursos Biológicos, CIRN, Instituto Nacional de Tecnología Agropecuaria (CNIA-INTA). Los Reseros y Las Cabañas s/n, 1712 Castelar, Provincia de Buenos Aires, Argentina.*
[4] *agoijman@cnia.inta.gov.ar*

ABSTRACT.— Birds play several roles in agricultural lands and respond to habitat heterogeneity within the agricultural landscape. Agricultural intensification in Argentina has increased the sown area, mainly with soybean, fragmenting landscapes in the pampas and mesopotamic region. In Entre Ríos Province, the original Espinal forest has been fragmented, leaving remnant patches of natural vegetation, in cases modified by cattle grazing. These changes represent a potential threat for avian conservation. In Entre Ríos, terraces may be a useful habitat in maintaining avian diversity, similar to other non-cropped linear habitats in agricultural landscapes. We tested the hypothesis that habitat heterogeneity created by terraces would maintain higher species richness and densities of avian species that use original or modified forests within cropped areas compared to fields without terraces. The study was carried out in soybean fields with an adjacent forest and either herbaceous, shrub or no terraces in two periods (March-April 2004). Birds were surveyed using line transects in field interior and edge, and observations were carried out in one forest remnant adjoining each field. Most bird species recorded in soybean fields were insectivorous or consume invertebrates during the breeding season. Species richness, total bird density and the density of granivores, insectivores and omnivores were higher in fields with terraces than in fields without terraces. Moreover, shrub terraces had higher effect on species richness and bird density than herbaceous terraces. Our results suggest that terraces may serve as a possible tool for maintaining avian diversity in agroecosystems in Entre Ríos.

KEY WORDS: *agricultural landscape, birds, forest, soybean, terraces.*

RESUMEN. EFECTOS DE LA HETEROGENEIDAD DEL HÁBITAT SOBRE LA DENSIDAD Y RIQUEZA DE AVES EN CAMPOS DE SOJA EN ENTRE RÍOS, ARGENTINA.— Las aves tienen varios roles en los agroecosistemas y responden a la heterogeneidad de hábitat dentro del paisaje agrícola. La intensificación agrícola en Argentina ha incrementado el área cultivada, principalmente con soja, fragmentando paisajes en la Región Pampeana y en la Región Mesopotámica. En la provincia de Entre Ríos, el bosque original del Espinal ha sido fragmentado, dejando parches remanentes de vegetación natural, en algunos casos modificados por el pastoreo del ganado. Estos cambios representan una amenaza para la conservación de aves. En Entre Ríos, las terrazas pueden ser un hábitat útil para mantener la diversidad de aves, como sucede con otros hábitats lineales. Se puso a prueba la hipótesis que la heterogeneidad de hábitat generada por las terrazas mantiene una mayor riqueza de especies y una mayor densidad de aves que usan bosques modificados u originales, comparado a campos sin terrazas. El estudio fue realizado en campos de soja con parches de bosque adyacente, con terrazas herbáceas, arbustivas y sin terrazas, en dos períodos (marzo-abril 2004). Las aves fueron muestreadas mediante transectas lineales en el interior y en el borde del cultivo, y se realizaron observaciones en un remanente de bosque adyacente a cada campo. La mayoría de las especies de aves registradas en los campos de soja son insectívoras o consumen invertebrados durante la época reproductiva. La riqueza de especies, la densidad total y la densidad de aves insectívoras, granívoras y omnívoras fueron mayores en campos con terrazas que en los campos sin terrazas. A su vez, las terrazas de composición arbustiva tuvieron mayor efecto sobre la riqueza y la densidad de aves que las terrazas herbáceas. Los resultados sugieren que las terrazas podrían servir como una posible herramienta para mantener la diversidad de aves en agroecosistemas en Entre Ríos.

PALABRAS CLAVE: *aves, bosque, paisaje agrícola, soja, terrazas.*

Received 24 September 2007, accepted 18 August 2008

Birds play several roles in agricultural lands and respond to habitat complexity and heterogeneity within the agricultural landscape. Some species are beneficial to agriculture because they consume large numbers of weed seeds and insects (Jones and Sieving 2006). Other species impact negatively on crops by consuming sprouts, seeds or leaves of valuable crops at different maturation stages (Bucher 1984, Kirk et al. 1996). Similarly, some species adapt well to simplified habitats where food resources are often only abundant during short periods of time (Wiens and Dyer 1977), while other species are sensitive to changes and simplification of habitat at local and landscape scales (Bennet 1999, Boutin et al. 1999).

To manage either the benefits of birds to agriculture or the damage they cause, it is important to understand how agricultural land management impacts avian communities and how agroecosystem attributes can be managed to maintain the ecological services that birds may provide (Daily 1997). In Europe and North America, vegetated edges of crop fields, other linear non-cropped habitats or intercrops within fields have demonstrated to maintain higher avian diversity when compared to more homogeneous agricultural landscapes (Kirk et al. 1996, Bennet 1999, Sieving et al. 2000, Boutin et al. 2001, Jobin et al. 2001, Jones and Sieving 2006).

Agricultural intensification in Argentina, particularly stemming from the use of herbicide tolerant soybeans and their related technologies, has more than doubled the area of land under soybean cultivation in approximately ten years (SAGPyA 2008). This increase in production acreage is a potential threat to biodiversity, because such expansion tends to homogenize agricultural landscapes. In Entre Ríos Province, farmers utilize contour terraces, which function to intercept runoff and reduce soil erosion (del Campo and Pearson 1998). Terraces are elevated strips of approximately 2 m width within fields, separated by different distances depending of field shape and slope. Sometimes terraces are cultivated or fumigated, but often not cultivated nor treated with herbicides. Based upon research in other regions (Sieving et al. 2000), linear elements as these may potentially be useful in conserving resources that maintain avian diversity in intensive agricultural habitats and may serve also as corridors for birds between suitable habitat patches.

We surveyed birds that use Espinal forests patches (either closed forests or open forests modified by cattle grazing), and surrounding soybean fields with and without terraces to test the hypothesis that habitat heterogeneity created by terraces would maintain higher avian diversity compared to fields without terraces. We focused on species which use forests because we consider these species to be the most affected by fragmentation or habitat simplification. We predicted that species richness and densities would be higher in fields with herbaceous and shrub terraces compared to those without terraces. We also examined whether there was a relationship between terraces and densities of avian foraging groups.

METHODS

Study area

The study was carried out in an agricultural landscape dominated by annual row crops and grazing lands in the Paraná Department, Entre Ríos Province, Argentina. This area supports Espinal forest, dominated by *Prosopis affinis*, *Acacia caven*, *Geoffroea decorticans*, *Celtis tala* and *Schinus longifolia* (Cabrera 1971). Most of the forests' patches are modified by cattle. Agricultural land use has fragmented the original forest, leaving remnant patches of natural vegetation in a matrix of agricultural land.

Experimental design

Within the study area we selected eight soybean fields near "El Palenque" (31°39'S, 60°12'W) and five near "Cerrito" (31°35'S, 60°05'W), separated by 13 km. The fields were surveyed during two periods in 2004 in order to capture the potential variability of bird preferences: (1) from 1 March until 9 March, when soybean was flowering, and (2) from 25 March until 2 April, during fruit formation. We categorized selected fields into three treatments: six fields without terraces, four fields none or little sprayed with herbicides with herbaceous terraces including some shrubs, and three fields with shrub vegetation terraces. The unbalanced number of fields per treatment depended on their availability in the study area.

All fields where under no-till management and adjacent to remnants of Espinal forest. To ensure independence, sites were at least 500 m apart (Ralph et al. 1996). We categorized field edges as herbaceous or herbaceous with woody vegetation or adjoining forest patches. During the survey, by contacting the producers, agricultural practices such as agrochemical applications that might affect the surveys where taken into account, avoiding counting birds, to maintain consistency among surveys.

Bird survey

Birds were surveyed using 100 m line transects assigned randomly to field interior and edge, while maintaining effort proportional to the field area and by field edge type (Fig. 1). Within each field two or three transects were located perpendicular to contour terraces ($n = 31$) and surveyed by two persons simultaneously. In field edges we assigned transects covering 30% of each edge type ($n = 65$). Birds were recorded within 10 m of each transect, defining that area as the crop edge. Transects in the field interior had an unlimited observational distance. We recorded distance (using a laser range finder) and the angle of observed birds in relation to the transect.

Point surveys were carried out in one forest remnant adjoining to each field, in order to document which species used the forest remnants (Fig. 1). We randomly located three points, separated 50 m from crop fields, where all birds seen or heard for 5 min periods were recorded (Ralph et al. 1996). We categorized bird use of forests and their diet based upon these observations and the descriptions given by Azpiroz (2003) and Narosky and Yzurieta (2003).

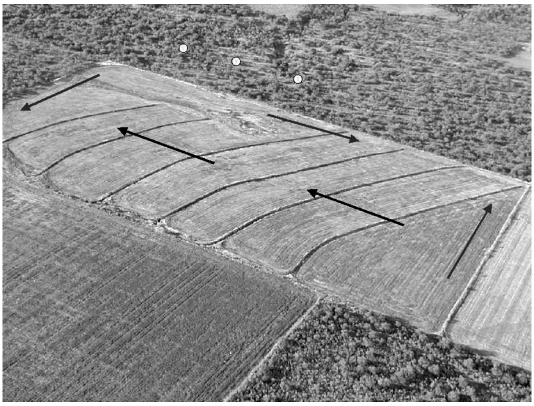

Figure 1. Typical soybean field surveyed in Paraná Department, Entre Ríos Province, Argentina. Black arrows show transects: three at field edge and two within the field interior, perpendicular to contour terraces. White spots show the location of the point counts in adjacent forest remnant.

Surveys were conducted for 3 h starting at sunrise and for 3 h prior to sunset. Extreme weather conditions like rain and strong wind were avoided with the purpose of reducing potential sources of error (Ralph et al. 1996, Bibby et al. 2000).

Data analysis

We surveyed each of the 13 fields in the first period, and 12 in the second period. We discarded one field with no terrace given the advanced soybean phenology of that field that had lost all their leaves and could introduce noise into the design.

We considered species richness per field, total avian density, as well as the densities of granivore, insectivore and omnivore birds as response variables.

We estimated density using a fixed-band transect index for field edges (Bibby et al. 2000) within 10 m from each side of the transect using the formula:

$$De = n / (2\, l\, w),$$

where n is the number of birds within w, w is the distance from centre to inner band (10 m), and l is transect length. In field interior we accounted for increased detectability by using a two-belt index (Greenwood 1996, Bibby et al. 2000) and calculating bird densities using the formula:

$$Df = [(n1 + n2) / (2\, l\, w)] \ln [(n1 + n2) / n2],$$

where $n1$ is the number of observations within w, $n2$ is the number of observations outside w, and w is the distance from centre to inner band (15 m; the distance within half the observations were made; Gibbons et al. 1996). We calculated bird density in each field by multiplying edge and interior densities by the proportions occupied by those habitats in each field, and then the products were summed, resulting in:

$$D = De\, Pe + Df\ Pf,$$

where Pe and Pf are the proportion of edge and field interior, respectively, in each field.

We calculated edge heterogeneity using the Shannon-Wiener diversity index (Donovan and Welden 2002) for the proportions of the three edge categories identified in each field: herbaceous, herbaceous with woody vegetation and adjoining forest patches.

Variation in bird species richness, total density and density for each foraging group were modelled in relation to the presence of terrace type, field area, field edge heterogeneity and survey period as covariates. We analyzed a set of *a priori* multiple linear regression models based on previous knowledge on avian ecology (Table 1), where it is known that bird density and richness might be affected negatively by field area and positively by heterogeneity (Best et al. 1990, Bennet 1999, Harvey et al. 2005). We determined the fit to normal distribution of the analyzed variables using a Lilliefors Test (Sokal and Rohlf 1995). We transformed total bird and insectivore densities using $y' = \ln(y + 1)$, and granivore and omnivore bird densities with $y' = \sqrt{y}$ in order to obtain a normal fit. Homogeneity of variance was tested with the Bartlett's Test considering terraces as treatments (Sokal and Rohlf 1995).

Models for each response variable were chosen based on the Akaike Information Criterion with the correction for small samples (*AICc*), considering the Δ*AICc* (i.e., the difference between a model's *AICc* value and the smallest *AICc* value for data set) and rankings by model weights for competitive and plausible models (Burnham and Anderson 2002). The strength of the effect of covariates was tested using 95% confidence intervals (95% CI) of the Regression Coefficient values (*B*). Where the confidence intervals crossed zero the effect of the covariate was considered to be small.

Table 1. *A priori* linear models selected to explain variation in total bird density, bird species richness and density of granivorous, insectivorous and omnivorous birds in soybean fields surveyed in Paraná Department, Entre Ríos Province, Argentina.

Data set	Variables [a]
Model 1	FHT, FST
Model 2	FHT, FST, Area
Model 3	FHT, FST, Heterog
Model 4	FHT, FST, Survey
Model 5	FHT, FST, Heterog, Area
Model 6	FHT, FST, Area, Survey
Model 7	FHT, FST, Heterog, Survey
Model 8	FHT, FST, Heterog, Area, Survey

[a] FHT: fields with herbaceous terraces, FST: fields with shrub terraces, Area: field area, Heterog: edge field heterogeneity, Survey: survey period.

RESULTS

We sampled 84.3 ha of fields without terraces, 100.7 ha of fields with herbaceous terraces and 41.2 ha of fields with shrub terraces. Average field size was 17.40 ± 9.23 ha. Total transect length for field interior and edge were 3100 m and 6500 m, respectively (herbaceous vegetation: 1500 m, shrub vegetation: 3000 m, adjacent to the forest: 2000 m).

We recorded a total of 39 species within soybean fields which are considered to use forest remnants or their edge (Table 2). For species recorded in soybean fields, 13 were considered to be granivorous, 21 insectivorous and 5 omnivorous. The most common species when data was pooled for field interior and edge from both surveys were Picui Ground-Dove (*Columbina picui*), Grassland Sparrow (*Ammodramus humeralis*), Rufous-Collared Sparrow (*Zonotrichia capensis*) and Brown-Chested Martin (*Progne tapera*). The frequency of occurrence for these species was higher than 20% (Fig. 2); 8 species showed frequencies of 2.5–20% and the other 27 species had frequencies <2.5%.

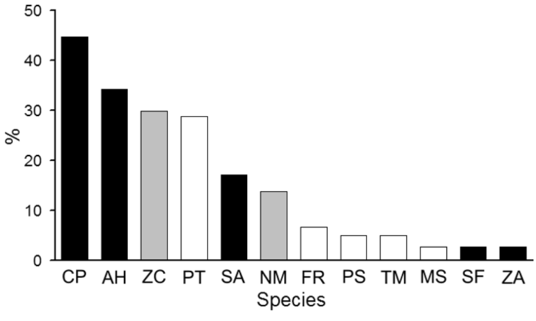

Figure 2. Frequency of occurrence of bird species in March and April 2004 in soybean fields surveyed in Paraná Department, Entre Ríos Province, Argentina, based on pooled data for field interior and edge. Black bars indicate granivorous species, white bars, insectivorous species, and grey bars, omnivorous species. CP: *Columbina picui*, AH: *Ammodramus humeralis*, ZC: *Zonotrichia capensis*, PT: *Progne tapera*, SA: *Saltator aurantiirostris*, NM: *Nothura maculosa*, FR: *Furnarius rufus*, PS: *Pitangus sulphuratus*, TM: *Troglodytes musculus*, MS: *Mimus saturninus*, SF: *Sicalis flaveola*, ZA: *Zenaida auriculata*.

Table 2. Avian species recorded in March and April 2004 within soybean fields surveyed in Paraná Department, Entre Ríos Province, Argentina. Avian use of forest remnants is indicated according to the survey in forest remnants adjacent to the field (FS), to transects in field edge adjoining to forest patches (TF) or to the description given by Narosky and Yzurieta (2003) (NY). "X" indicates where the information was taken from. Food habits are indicated based on previous knowledge, observations and descriptions in Azpiroz (2003).

Family	Species	FS	TF	NY	Food habit
Tinamidae	*Nothura maculosa*		X		Omnivore
Columbidae	*Columbina picui*	X	X	X	Granivore
Columbidae	*Leptotila verreauxi*	X	X	X	Granivore
Columbidae	*Zenaida auriculata*	X	X	X	Granivore
Psittacidae	*Myiopsitta monachus*	X		X	Granivore
Cuculidae	*Guira guira*			X	Insectivore
Trochilidae	*Chlorostilbon aureoventris*	X		X	Insectivore
Picidae	*Colaptes melanochloros*			X	Insectivore
Dendrocolaptidae	*Lepidocolaptes angustirostris*	X	X	X	Insectivore
Furnaridae	*Coryphistera alaudina*			X	Insectivore
Furnariidae	*Furnarius rufus*	X	X	X	Insectivore
Furnariidae	*Phacellodomus sibilatrix*			X	Insectivore
Furnariidae	*Pseudoseisura lophotes*	X	X	X	Insectivore
Furnariidae	*Schoeniophylax phryganophilus*			X	Insectivore
Furnariidae	*Synallaxis albescens*	X		X	Insectivore
Formicariidae	*Taraba major*	X	X	X	Insectivore
Tyrannidae	*Lathrotriccus euleri*			X	Insectivore
Tyrannidae	*Pitangus sulphuratus*	X	X	X	Insectivore
Tyrannidae	*Pyrocephalus rubinus*			X	Insectivore
Tyrannidae	*Tyrannus savana*	X		X	Insectivore
Tyrannidae	*Xenopsaris albinucha*		X	X	Insectivore
Tyrannidae	*Xolmis irupero*			X	Insectivore
Hirundinidae	*Progne tapera*	X	X	X	Insectivore
Troglodytidae	*Troglodytes musculus*	X	X	X	Insectivore
Mimidae	*Mimus saturninus*	X		X	Insectivore
Sylviidae	*Polioptila dumicola*	X	X	X	Insectivore
Thraupidae	*Thraupis sayaca*			X	Omnivore
Emberizidae	*Ammodramus humeralis*	X	X		Granivore
Emberizidae	*Coryphospingus cucullatus*			X	Granivore
Emberizidae	*Embernagra platensis*	X	X		Granivore
Emberizidae	*Poospiza melanoleuca*			X	Granivore
Emberizidae	*Poospiza nigrorufa*	X		X	Granivore
Emberizidae	*Saltator aurantiirostris*	X	X	X	Granivore
Emberizidae	*Saltatricula multicolor*		X	X	Granivore
Emberizidae	*Sicalis flaveola*	X		X	Granivore
Emberizidae	*Sicalis luteola*		X		Granivore
Emberizidae	*Sporophila* sp.				Granivore
Emberizidae	*Zonotrichia capensis*	X	X	X	Omnivore
Icteridae	*Molothrus badius*	X	X	X	Omnivore
Icteridae	*Molothrus rufoaxillaris*	X	X	X	Omnivore
Icteridae	*Sturnella superciliaris*				Omnivore

Avian density was best explained by the model that only includes the presence of terraces as explanatory variable (Table 3). The second and third best models included field area and heterogeneity, respectively, in addition to terraces. There was a weak positive effect of herbaceous terraces (B = 0.17, 95%CI = -0.32–1.11) and a strong positive effect of shrub terraces (B = 0.92, 95%CI = 1.10–2.51). Regression Coefficient for field area had a low and negative effect (B = -0.03, 95%CI = -0.02–-0.10) and was weak for het-

Table 3. *A priori* models for total bird density and bird species richness recorded in March and April 2004 in soybean fields surveyed in Paraná Department, Entre Ríos Province, Argentina, compared with Akaike's Information Criterion (n = 13). K is the number of model parameters (K = constant + variables + error term), and *Wi* represents the model's *AICc* weight relative to all models in the data set (where all models weights sum to 1).

Data set	Variables [a]	K	*Adjusted* R^2	Δ*AICc*	*Wi*
Density	FHT, FST	4	0.166	0.00	0.41
Density	FHT, FST, Area	5	0.198	1.03	0.24
Density	FHT, FST, Heterog	5	0.160	2.17	0.14
Density	FHT, FST, Survey	5	0.129	3.11	0.09
Richness	FHT, FST	4	0.435	0.00	0.47
Richness	FHT, FST, Survey	5	0.442	1.67	0.20
Richness	FHT, FST, Area	5	0.416	2.81	0.11
Richness	FHT, FST, Heterog	5	0.416	3.03	0.10

[a] FHT: fields with herbaceous terraces, FST: fields with shrub terraces, Area: field area, Heterog: edge field heterogeneity, Survey: survey period.

erogeneity (B = -0.48, 95%CI = -1.94–0.08). Total bird density was higher in fields with shrub terraces than in fields with herbaceous terraces and without terraces (Fig. 3).

Avian species richness also was best explained by the model including terraces as the only variable (Table 3). Survey period was included in the second best model and field area

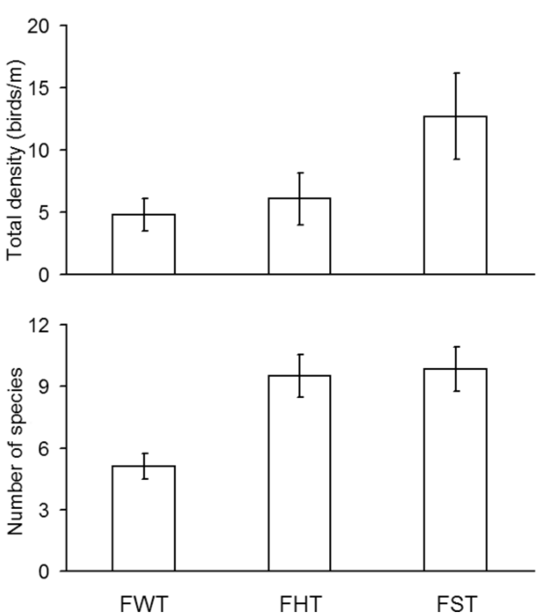

Figure 3. Mean (± SE) total bird density (above) and bird species richness (below) in soybean fields without terraces (FWT), fields with herbaceous terraces (FHT) and fields with shrub terraces (FST) in March and April 2004 in Paraná Department, Entre Ríos Province, Argentina.

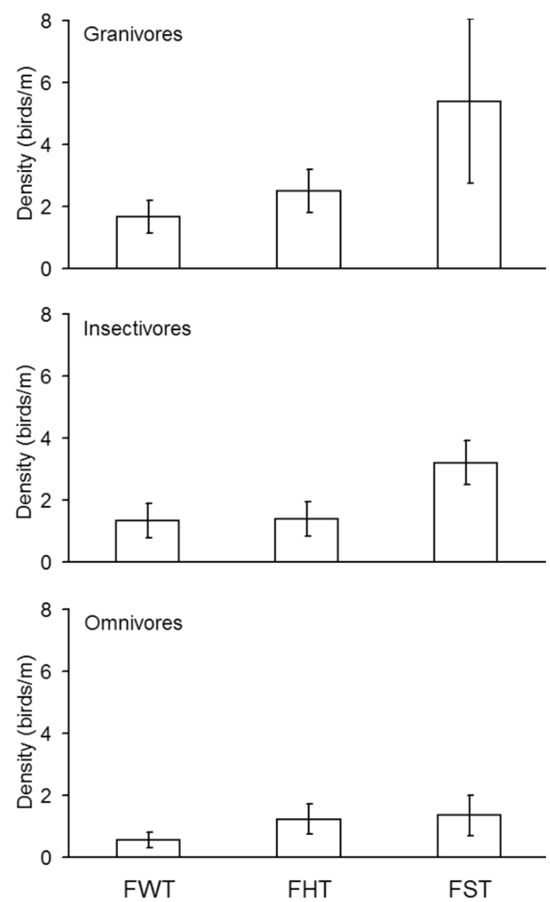

Figure 4. Mean (± SE) density of granivorous birds (above), insectivorous birds (center), and omnivorous birds (below) in soybean fields without terraces (FWT), fields with herbaceous terraces (FHT) and fields with shrub terraces (FST) in March and April 2004 in Paraná Department, Entre Ríos Province, Argentina.

Table 4. *A priori* models for density of granivorous, insectivorous and omnivorous birds recorded in March and April 2004 in soybean fields surveyed in Paraná Department, Entre Ríos Province, Argentina, compared with Akaike's Information Criterion (n = 13). K is the number of model parameters (K = constant + variables + error term), and Wi represents the model's $AICc$ weight relative to all models in the data set (where all models weights sum to 1).

Data set	Variables [a]	K	*Adjusted* R^2	$\Delta AICc$	Wi
Granivores	FHT, FST	4	0.116	0.00	0.50
Granivores	FHT, FST, Heterog	5	0.113	2.09	0.18
Granivores	FHT, FST, Area	5	0.089	2.73	0.13
Granivores	FHT, FST, Survey	5	0.074	3.15	0.10
Insectivores	FHT, FST, Area	5	0.259	0.00	0.29
Insectivores	FHT, FST	4	0.180	0.52	0.23
Insectivores	FHT, FST, Area, Survey	6	0.276	1.70	0.13
Insectivores	FHT, FST, Heterog	5	0.206	1.72	0.12
Insectivores	FHT, FST, Survey	5	0.179	2.54	0.08
Insectivores	FHT, FST, Heterog, Area	6	0.247	2.67	0.08
Insectivores	FHT, FST, Heterog, Survey	6	0.211	3.84	0.04
Omnivores	FHT, FST	4	0.057	0.00	0.43
Omnivores	FHT, FST, Survey	5	0.069	1.67	0.19
Omnivores	FHT, FST, Area	5	0.056	2.03	0.16
Omnivores	FHT, FST, Heterog	5	0.018	3.03	0.09

[a] FHT: fields with herbaceous terraces, FST: fields with shrub terraces, Survey: survey period, Area: field area, Heterog: edge field heterogeneity.

in the third one, both in addition to terraces. Regression Coefficient was positive for herbaceous (B = 4.41, 95%CI = 6.36–10.9), shrub terraces (B = 4.74, 95%CI = 6.80–11.78) and survey (B = 1.13, 95%CI = 0.26–4.17). The effect of field area was positive but weak (B = 0.04, 95%CI = -0.07–0.23). Avian richness was similar in fields with herbaceous and shrub terraces, and higher than in fields with no terraces (Fig. 3).

The best model explaining granivore densities include terraces as the only variable. Heterogeneity, field area and survey period also explained a proportion of variation in granivore density (Table 4). The effect of herbaceous terraces was weak (B = 0.3, 95%CI = -0.14–0.46), positive for shrub terraces (B = 0.4, 95%CI = 1.00–2.74) and negative for heterogeneity (B = -0.55, 95%CI = -2.2–-3.19) and field area (B = -0.01, 95%CI = -0.07–-0.10). Granivore densities were higher in fields with shrub terraces than in fields with herbaceous terraces and fields with no terraces (Fig. 4).

Insectivore densities were best explained by the model including the presence of terraces and field area; the second model included only terraces (Table 4). Survey period and field heterogeneity explained a proportion of variation in insectivore densities. Regression Coefficient was positive for herbaceous (B = 0.41, 95%CI = 0.68–0.21) and shrub terraces (B = 0.73, 95%CI = 1.94–0.92), negative for field area (B = -0.03, 95%CI =-0.03–-0.09), survey period (B = -0.25, 95%CI = -0.09–-0.89) and heterogeneity (B = -0.50, 95%CI = -0.23–-1.74). Insectivore densities were higher in fields with shrub terraces than in fields with herbaceous terraces and fields with no terraces (Fig. 4).

The model explaining omnivore densities included only the presence of herbaceous and shrub terraces as the best explanatory variables (Table 4). Survey period and field area also explained a proportion of variation in omnivore densities. Regression Coefficient was positive for herbaceous terraces (B = 0.47, 95%CI = 0.36–1.27), shrub terraces (B = 0.45, 95%CI = 0.26–1.12) and survey period (B = 0.28, 95%CI = 0.07–0.61), and negative for field area (B = -0.02, 95%CI = -0.07–-0.10). Omnivore densities were similar in fields with and without terraces (Fig. 4).

DISCUSSION

Birds frequently detected in soybean fields and in the forest remnants were species commonly found in human environments, including Rufous Hornero (*Furnarius rufus*), Picui Ground-Dove, Rufous-Collared Sparrow and Eared Dove (*Zenaida auriculata*). This pattern was consistent with those found by Canavelli et al. (2004) in south-central Entre Ríos Province in Argentina and Boutin et al. (1999) in Canadian agroecosystems. Although some species like Grassland Sparrow, Spotted Nothura (*Nothura maculosa*) and Grassland Yellow-Finch (*Sicalis luteola*) are not typical forest species, and they are common in agricultural environments (Azpiroz 2003, Narosky and Yzurieta 2003), they were observed in forest remnants adjacent to soybean fields or at field forest edges. Apart from the species recorded during the surveys, we saw four individuals of Yellow Cardinal (*Gubernatrix cristata*). This species is considered endangered by BirdLife International (2004), therefore it is important to note the value of conserving habitat for this species.

Most bird species recorded in soybean fields were insectivorous or consume invertebrates during the breeding season (Capurro and Bucher 1982, Azpiroz 2003). The only exclusively granivorous species abundant in soybean fields were Picui Ground-Dove and Eared Dove (Capurro and Bucher 1982, Bucher 1990), and only the latter is considered a problematic species in agroecosystems (Bruggers and Zaccagnini 1994).

Fields with terraces maintained higher bird species richness and density than fields without terraces and, based on our modelling, they contributed more to the variation in species richness and density than field size, heterogeneity or survey period. The importance of vegetated field terraces for the maintenance of avian species richness and density within soybean fields was further illustrated by Solari (2006) who found no difference between field interior and terraces in terraces treated with herbicides. These results are consistent with other studies demonstrating the importance of non-cropped linear habitats (e.g., field edges, windbreaks) or intercropping in increasing species diversity (Kirk et al. 1996, Bennet 1999, Harvey et al. 2005, Jones and Sieving 2006).

Total bird density was higher in fields with shrub terraces compared to fields with herbaceous terraces; the same pattern emerges when looking at densities of insectivorous and granivorous species. This result is expected for ecologically plastic forest species, area-insensitive and immersed in an agricultural matrix (Dardanelli et al. 2006). The weak positive response of total density to herbaceous terraces could be explained by the variability in density of granivorous birds in those fields, and may be attributable to greater sensitivity of this group to variation in vegetation structure compared to the other groups (Wiens and Johnston 1977). The greater effect of shrub terraces on insectivore density compared to herbaceous terraces and fields without terraces may be due to increased invertebrate food resources stemming from more complex vegetation structure (Thomas and Marshall 1999).

Field area promoted a detriment in total bird density and in the density of the different groups as it was expected by previous knowledge on avian ecology. This result is consistent with Best et al. (1990) who found that larger fields are used proportionally less by birds in cornfields, because of the proportion of linear field edge decreases as field size increases. Edge heterogeneity negatively impacted insectivore and granivore densities, which was opposite than expected. Increasing heterogeneity in some fields was related to a decreasing proportion of shrub edge and proximity to forest edges, which decreases vegetative structure. This has been documented to be related to decreases in bird densities in linear non-cropped habitats and may explain the unexpected results (Boutin et al. 2001, Jobin et al. 2001, Jones et al. 2005). Survey period effect upon avian richness and densities was variable. While the number of species and omnivore densities increased, insectivore densities decreased. This last result may be explained by the coincidence of the beginning of the migration period of some insectivore species, as Brown-Chested Martin and Fork-tailed Flycatcher (*Tyrannus savana*), in the second survey period.

This study has focused in 13 fields within an agricultural matrix. Although they might seem to be insufficient, they satisfied standard conditions of crop growth and the necessary condition of being surrounded by forest patches.

We consider that the results are representative of the agroecosystem matrix considered. Therefore, extrapolation to a landscape with different characteristics must be taken carefully. It is also important to notice that this study has focused on the heterogeneity provided by contour terraces for species using soybean fields within a matrix of modified Espinal forest remnants. To look at the conservation value of contour vegetated terraces or to assess their benefit for the connectivity of forest patches for forest-specialist species, a more thorough study on the use of terraces by these species should be done.

In sum, our results suggest that heterogeneity generated by terraces within soybean fields enhance bird richness and density, therefore terraces may serve as a possible tool for maintaining avian diversity in agroecosystems in Entre Ríos. However, terraces with shrub vegetation are undesirable by many farmers and are often treated with herbicides to prevent encroachment of trees and shrubs. Because terraces with herbaceous vegetation also maintain bird species richness and a proportion of density, and a significant portion of these species consume invertebrates, herbaceous terraces may make a considerable contribution to pest management (Jones et al. 2005).

ACKNOWLEDGEMENTS

This study is part of the project "Ecotoxicological monitoring of biodiversity in agroecosystems" financed by National Institute of Agricultural Technology (INTA) and the United States Fish and Wildlife Service (USFWS–NMBCA-#2534). We thank to INTA Paraná Experimental Station, by providing facilities for this study. Agriculture producers allowed us to use their fields: Sangoy family, M. Schalpeter, R. Bollo, the "Agropecuaria El Encuentro", M. Villarraza, E. and A. Gadi-Hillairet, V. Beltramino and C. Martins Mogo. L. Solari cooperated in field surveys and design. J. Decarre, R. Suárez, F. Weyland, A. Álvarez Rosón and V. Della Torre shared field work. S. Canavelli and N. Calamari advised in survey methodology and analysis. Jeffrey Thompson helped editing this manuscript. B. Jauberts, J. L. Cappellacci and P. Cansio assisted in field work. J. L. Panigatti, R. De Carli and W. Mancuso provided very useful agronomic and soil conservation information. Dr. David Anderson provided insights for data modelling and analysis. V. Bressia helped with statistical analysis. J. Lopez de Casenave, V. Cueto and V. Massoni provided very useful comments in the Goijman's thesis manuscript.

LITERATURE CITED

AZPIROZ AB (2003) *Aves del Uruguay. Lista e introducción a su biología y conservación.* Aves Uruguay-GUPECA, Montevideo

BENNET AF (1999) *Linkages in the landscape. The role of corridors and connectivity in wildlife conservation.* IUCN, Gland and Cambridge

BEST LB, WHITMORE RC AND BOOTH GM (1990) Use of cornfields by birds during the breeding season: the importance of edge habitat. *American Midland Naturalist* 123:84–99

BIBBY CJ, BURGESS ND, HILL DA AND MUSTOE S (2000) *Bird census techniques*. Academic Press, London

BIRDLIFE INTERNATIONAL (2004) *Threatened birds of the world 2004*. BirdLife International, Cambridge

BOUTIN C, FREEMARK KE AND KIRK DA (1999) Spatial and temporal patterns of bird use of farmland in Southern Ontario. *Canadian Field Naturalist* 113:430–443

BOUTIN C, JOBIN B, BÉLANGER L, BARIL A AND FREEMARK KE (2001) Hedgerows in the farming landscapes of Canada. Pp. 33–42 in: BARR C AND PETIT S (eds) *Hedgerows of the world: their ecological functions in different landscapes. Proceedings of the Annual IALE (UK) Conference held at the University of Birmingham.* International Association for Landscape Ecology – UK Region, Lymm

BRUGGERS RL AND ZACCAGNINI ME (1994) Vertebrate pest problems related to agricultural production and applied research in Argentina. *Vida Silvestre Neotropical* 3:71–83

BUCHER EH (1984) *Las aves como plaga en la Argentina*. Centro de Zoología Aplicada, Universidad Nacional de Córdoba, Córdoba

BUCHER EH (1990) The influence of changes in regional land-use patterns on *Zenaida* dove populations. Pp. 291–303 in: PINOWSKI J AND SUMMERS-SMITH JD (eds) *Granivorous birds in the agricultural landscape*. INTECOL, Warsaw

BURNHAM KP AND ANDERSON DA (2002) *Model selection and multimodel inference. A practical information-theoretic approach*. Second edition. Springer, New York

CABRERA AL (1971) Fitogeografía de la República Argentina. *Boletín de la Sociedad Argentina de Botánica* 14:1–42

DEL CAMPO HE AND PEARSON F (1998) La erosión hídrica y su control con terrazas de desagüe paralelizadas. Pp. 101–162 in: DEL CAMPO HE AND PEARSON F (eds) *Erosión: sistemas de producción, manejo y conservación del suelo y del agua.* Fundación Cargill, Buenos Aires

CANAVELLI SB, ZACCAGNINI ME, TORRESIN J, CALAMARI NC, DUCOMMUN MP AND CAPLLONCH P (2004) Monitoreo extensivo de aves en el centro-sur de Entre Ríos. Pp. 349–362 in: ACEÑOLAZA FG (ed) *Temas de la biodiversidad del litoral fluvial argentino.* Instituto Superior de Correlación Geológica, San Miguel de Tucumán

CAPURRO HA AND BUCHER EH (1982) Poblaciones de aves granívoras y disponibilidad de semillas en el bosque chaqueño de Chamical. *Ecosur* 9:117–131

DAILY AB (1997) *Nature's services: societal dependence on natural ecosystems*. Island Press, Washington DC

DARDANELLI S, NORES ML AND NORES M (2006) Minimum area requirements of breeding birds in fragmented woodland of Central Argentina. *Diversity and Distributions* 12:687–693

DONOVAN TM AND WELDEN CW (2002) *Spreadsheet exercises in conservation biology and landscape ecology.* Sinauer Associates, Sunderland

GIBBONS DW, HILL D AND SUTHERLAND WJ (1996) Birds. Pp. 227–259 in: SUTHERLAND WJ (ed) *Ecological census techniques, a handbook*. Cambridge University Press, Cambridge

GREENWOOD JD (1996) Basic Techniques. Pp. 11–110 in: SUTHERLAND WJ (ed) *Ecological census techniques, a handbook*. Cambridge University Press, Cambridge

HARVEY CA, VILLANUEVA C, VILLACÍS J, CHACÓN M, MUÑOZ D, LÓPEZ M, IBRAHIM M, GÓMEZ R, TAYLOR R, MARTÍNEZ J, NAVAS A, SAENZ J, SÁNCHEZ D, MEDINA A, VILCHEZ S, HERNÁNDEZ B, PÉREZ A, RUIZ F, LÓPEZ F, LANG I AND SINCLAIR FL (2005) Contribution of live fences to the ecological integrity of agricultural landscapes. *Agriculture Ecosystems and Environment* 111:200–230

JOBIN B, CHOINIERE L AND BÉLANGER L (2001) Bird use of three types of field margins in relation to intensive agriculture in Québec, Canada. *Agriculture Ecosystems and Environment* 84:131–143

JONES GA AND SIEVING KE (2006) Intercropping sunflower in organic vegetables to augment bird predators of arthropods. *Agriculture Ecosystems and Environment* 117:171–177

JONES GA, KE SIEVING AND SK JACOBSON (2005) Avian diversity and functional insectivory on North-Central Florida farmlands. *Conservation Biology* 19:1234–1245

KIRK DA, EVEDEN MD AND MINEAU P (1996) Past and current attempts to evaluate the role of birds as predators of insect pests in temperate agriculture. *Current Ornithology* 13:175–269

NAROSKY T AND YZURIETA D (2003) *Guía para la identificación de las aves de Argentina y Uruguay*. Edición de Oro. Váquez Mazzini Editores, Buenos Aires

RALPH CJ, GEUPEL GR, PYLE P, MARTIN TE, DESANTE DF AND MILÁ B (1996) *Handbook of field methods for monitoring landbirds.* USDA Forest Service General Technical Report PSW-GTR-159, Albany

SAGPYA (2008) *Estimaciones agrícolas. Informes generales por cultivo: soja*. Secretaría de Agricultura, Ganadería, Pesca y Alimentos, Ministerio de Economía y Producción de la República Argentina, Buenos Aires

SIEVING KE, WILLSON MF AND DE SANTO TL (2000) Defining corridor functions for endemic birds in fragmented south-temperate rainforest. *Conservation Biology* 14:1120–1132

SOKAL RR AND ROHLF FJ (1995) *Biometry*. WH Freeman, New York

SOLARI LM (2006) *Homogeneidad ambiental por monocultivo de soja y su efecto en las aves*. Tesis de licenciatura, Universidad de Buenos Aires, Buenos Aires

THOMAS CFJ AND MARSHALL EJP (1999) Arthropod abundance and diversity in differently vegetated margins of arable fields. *Agriculture Ecosystems and Environment* 72:131–144

WIENS JA AND DYER MI (1977) Assessing the potential impact of granivorous birds in ecosystems. Pp. 205–264 in: PINOWSKI J AND KENDEIGH SC (eds) *Granivorous birds in ecosystems*. Cambridge University Press, Cambridge

WIENS JA AND JOHNSTON RF (1977) Adaptive correlates of granivory in birds. Pp. 301–340 in: PINOWSKI J AND KENDEIGH SC (eds) *Granivorous birds in ecosystems*. Cambridge University Press, Cambridge